SEMI-AUTOMATED MAPPING OF LANDSLIDE CHANGES IN TAIWAN BY MEANS OF OBJECT-BASED IMAGE ANALYSIS

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ABSTRACT

Earth observation (EO) data are of great value for the detection of landslides after triggering events, especially if they occur in remote and hardly accessible terrain. To fully exploit the potential of the wide range of available remote sensing data, innovative and reliable landslide (change) detection methods are needed. To overcome the limitations of pixel-based methods object-based image analysis (OBIA) has recently been employed for EO-based landslide (change) mapping. The presented approach is developed for a sub-area of the Baichi catchment in northern Taiwan. The focus is on themapping oflandslides and debris flows/sediment transport areascaused by the Typhoons Aere in 2004 and Matsa in 2005. For both events, pre- and post-disaster optical satellite images (SPOT-5 with 2.5 m spatial resolution)were analysed. A digital elevation model (DEM)at 5 m spatial resolution and its derivatives, mainly slope and curvature, were integrated in the analysis to support the semi-automated object-based mapping.The changes were identified by comparing properties of segmentation-derived image objects between pre- and post-event images. To ensure a certain degree of transferability and robustness of the approach changes were mainly detected using relational features such as the Normalized Difference Vegetation Index (NDVI) and the Green Normalized Difference Vegetation Index (GNDVI).

INTRODUCTION

Traditionally, pixel-based approaches are predominantly used for mapping changes based on high resolution (HR) or very high resolution (VHR) satellite imagery (1,2). Yet, pixel-based methods only analyse the change in spectral values for the same pixel locations in multi-temporal images. The salt-and-pepper effect in the resulting (change) maps significantly reduces the ability of pixel-based techniques to adequately depict changes of natural phenomena such as landslides. To overcome these limitations object-based image analysis (OBIA) has recently been employed for EO-based change mapping (1). Apart from spectral characteristics, OBIA allows the utilisation of spatial, contextual and morphological properties. Due to the reduced relevance of spectral information, atmospheric and radiometric correction of images is less important for object-based change detection. However, only few studies have shown the potential of OBIA for landslide change mapping.A semi-automatic object-oriented change detection approach using VHRoptical satellite imagery for landslide rapid mapping was developed by Lu et al. (3).Anders et al. (4) used LiDAR digital terrain models for geomorphological change analysis. Martha et al. (5) suggested an approach based on brightness changes in pre- and post-event panchromatic images for the creation of historical landslide inventories.Park and Chi (6) used an object-based change detection approach to locate landslide-prone areas.

The main objective of this study is to semi-automatically detect and classify typhoon-induced landslide changes based on pre- and post-event satellite images.Mass movements were classified into “landslides” and “debris flows/sediment transport areas” to allow for theidentification of class-specific changes.

METHODS

Study area

The presented approach was developed for a sub-area of the Baichi catchment, which is located in the Shihmen Reservoir watershed in northern Taiwan (Figure 1). The island of Taiwan is situated in the tropical and sub-tropical climate zones. During summer and autumn, especially from July to October, Taiwan is regularly affected by typhoons. The heavy rainfalls associated with these tropical storms often cause numerous landslides and debris flows, leading to fatalities and severe damages of infrastructure. The study site covers an area of approximately 16 km² and is characterized by mountainous terrain with steep slopes that are highly susceptible to mass movements. The focus of this study is on the semi-automated (change) mapping of landslides and debris flows/sediment transport areas caused by the Typhoons Aere (August 23-26, 2004) and Matsa (August 3-6, 2005), respectively.Manual interpretation of post-event orthophotos showed that Typhoon Aere caused 703 landslides in the Shihmen Reservoir watershed (7), whereof 421 landslides occurred in the Baichi catchment(8,9).Typhoon Aere brought more than 1,600 mm and Typhoon Matsa over 1,200 mm of accumulated rainfall to the Shihmen Reservoir watershed, whereby especially the Baichi and Yufeng catchments were heavily affected (10). Statistically, such a heavy rainfall event occurs in Baichi only once every 100 years (10).

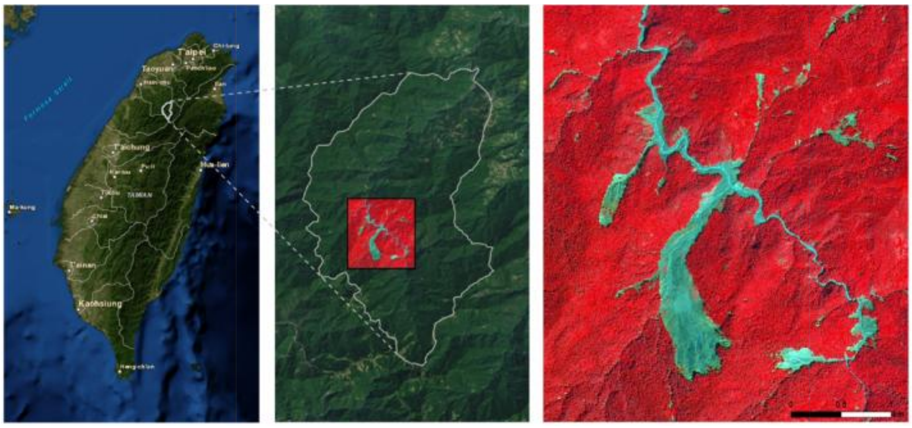

Figure 1: Study area: overview of Taiwan with the Baichi catchment (grey polygon; left); Baichi catchment and location of the study site(centre); SPOT-5 image (acquisition date: 09/09/2005; after Typhoon Matsa) showing the study area (right).

Data

Pre- and post-event SPOT-5 images with three spectral bands (green, red, near infrared) and a spatial resolution of 2.5 m were used for the mapping of landslides and landslide changes. The SPOT-5 images represent the status quo before and after the Typhoons Aere and Matsa. Additionally, a digital elevation model (DEM) with 5 m spatial resolution and its derivativeswere integrated in the analysis to support the semi-automated (change) mapping of landslides and debris flows/sediment transport areas (see Table 1).

Table 1: Remote sensing data for the sub-area of the Baichi catchment.

Data	Description	Spatial resolution	Acquisition data
SPOT-5	Pre-event image: Typhoon Aere	2.5 m	10/02/2004
	Post-event image: Typhoon Aere	2.5 m	02/11/2004
	Pre-event image: Typhoon Matsa	2.5 m	16/03/2005
	Post-event image: Typhoon Matsa	2.5 m	09/09/2005
DEM	Pre-event data;	5 m	Derived from orthophotos

	Including DEM derivatives: slope, curvature, plan curvature, profile curvature		taken in 2002 and 2003

Object-based classification on post-event optical data

The semi-automated object-based classification of landslides and debris flows/sediment transport areas was based on the post-event SPOT-5 image from 2005 and the 5 m DEM including its derivatives. Image analysis was conducted in eCognition (Trimble) software. First, additional layers (brightness, Normalized Difference Vegetation Index - NDVI, Green Normalized Difference Vegetation Index - GNDVI) were calculated. The selection of an appropriate scale parameter for multiresolution segmentation was supported by using the Estimation of Scale Parameter 2 (ESP 2) tool. ESP 2 identifies statistically relevant image object levels for a set of input layers(11).A scale parameter of 32 was finally selected for multiresolution segmentation of SPOT-5 bands, the NDVI and brightness layers. Subsequently,the NDVI and brightness were used for the recognition of areas affected by mass movements. The absence of vegetation,and thus, the presence of bare ground wereassumed to be an evidence for the occurrence of mass movements.As debris flows/sediment transport areas showed non-uniform spectral features, they were mainly differentiated from landslidesbymorphological characteristics.Sincedebris flows/sediment transporttake placemost likely along stream channels, anindependent segmentation of plan curvature and slope was performed.Objects with low curvature values were then classified as concave terrain. Additional object features(e.g. slope, relative border to neighbouring objects) were used to enhance the extraction of stream channels.Results were synchronized with the potential mass movement areas previously classified, and addressed as debris flows/sediment transport areas from now on.Noteworthy, this class includes also the larger river beds where the downstream transportation of debris and sedimentsoccurs. The remaining areas affected by mass movements were treated as landslides. The two classes were further refined by using spatial (e.g. area, shape) and contextual parameters (e.g. relative border to neighbouring objects) to eliminatefalse positives with spectral properties similar to mass movement areas (e.g. paths, harvested agricultural fields, cleared bamboo forest). The boundaries of the classified image objects werefinally smoothed by growing and shrinking operations.

The described approach was transferred to the post-event SPOT-5 image from 2004, which shows radiometric differences compared to the one from 2005. The vegetation appears to be darker and more shadows are present. Nevertheless, the developed ruleset could be transferred with only minor adaptations. The obtained classification results served as input for the class-specific object-based change detection.

Class-specific change detection

The class-specific object-based change detection was first accomplishedfor theTyphoon Matsa event (2005) and then transferred to the images available for the Typhoon Aere (2004). The typhoon-triggered landslides and debris flows/sediment transport areas were identified by comparing the properties of segmentation-derived image objects between the respective pre- and post-event images. The loss of vegetation served as proxy for the occurrence of mass movements. Vegetation loss wasidentified by a negative change of the NDVI and the GNDVI. As the quality and radiometric characteristics of the pre- and post-event images differ (mainly because of different acquisition dates during the year), normalization factors were calculated to normalize thevegetation indices across the two images.This was done by dividing the value of the post-eventNDVI and GNDVI, respectively, by the value of the corresponding pre-event index. As next step, a joint multiresolution segmentation on both images from 2005 was carried out using the bands of the SPOT-5 imagesand the NDVI layers. Again, the selection of an appropriate scale parameter, in this case 31, was supported by the statistical evaluation with the ESP 2 tool. Each of the resulting objects was then investigated in respect of its transformation between the two points in time. By multiplying theoriginalpre-event NDVI and GNDVIwith the corresponding normalization factor theywere adapted to the post-event indices to enable an objective comparison of values.Next, the post-event NDVI and GNDVI were subtracted from the corresponding adapted pre-event index. If the resulting value was higher than adefined threshold,the objects were classified as affected by a change. The introduction of such a threshold was necessary to prevent the classification of objects which showed only minor value changes. A second condition was applied to detect only those objects with a relatively low NDVI value in the post-event image. As a result, areas which had been affected by a change in vegetation, but which were still vegetated, could be excluded. Finally, the objects affected by change were synchronized with the prior established classification of landslides and debris flow/sediment transport areas to assess class-specific changes.

RESULTS

Landslides and debris flows/sediment transport areas could be accurately classified and changes were efficiently detected. Taiwanese landslide experts confirmed the validity of the results during recent workshops and personnel discussions. Figure 2 shows the results of the semi-automated object-based classification of landslides and debris flows/sediment transport areas for the post-event images from 2004 and 2005.

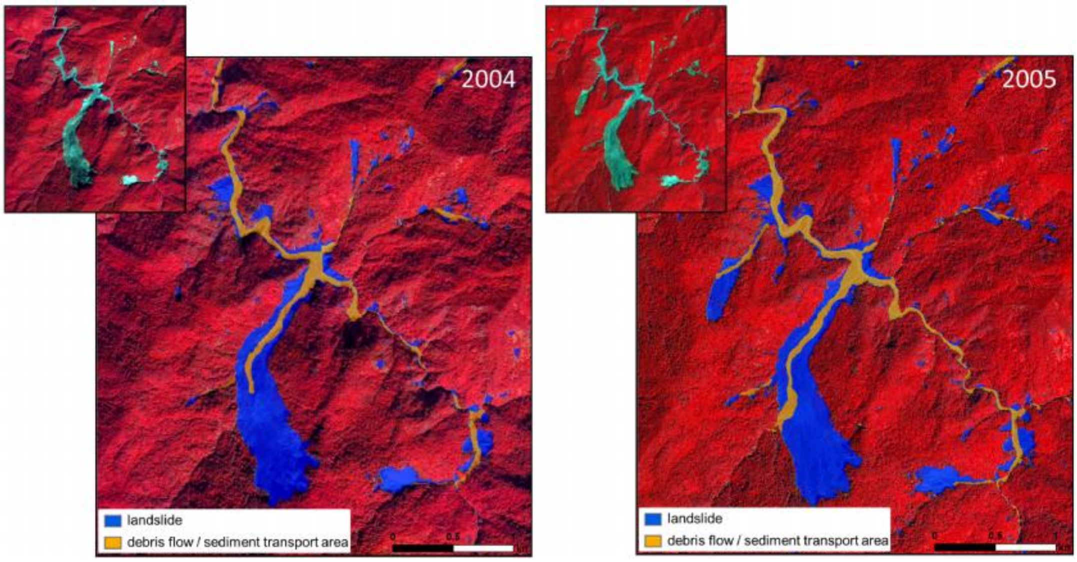

Figure 2: Classification result showing the detected landslides and debris flows/sediment transport areas after Typhoon Aere (2004; left) and after Typhoon Matsa (2005; right).

For quantitatively assessing the accuracy, the classification results were compared to a landslide inventory that was produced by local landslide experts through manual interpretation of orthophotos (see Table 2).As the reference data set does not include debris flows or other sediment transport areas, only the accuracy of the detected landslides was assessed.In general, the semi-automated classification overestimates the reference; the deviationbetween the semi-automatically classified landslides and the reference accounts to approximately 20 % for 2004 and about 24 % for 2005.

Table 2: Classification results (in hectare) for the post-event images from 2004 and 2005 and producer's and user's accuracy for the class "landslide".

	Class	Classification (in ha)	Reference (in ha)	Correctly classified areas(in ha)	Producer's accuracy (in %)	User's accuracy (in %)
Area (2004)	Landslide	96.42	80.08	68.04	84.97	70.57
	Debris flows/ sediment	34.67	n/a	n/a	n/a	n/a

	transport area					
Matsa (2005)	Landslide	112.57	90.6	76.28	84.19	67.76
	Debris flows/ sediment transport area	49.01	n/a	n/a	n/a	n/a

The results of the class-specific change detection (see Figure 3) revealed thatapproximately 58.5 % of areas affected by landslides and 36.5 % of the debris flows/sediment transport areas detected in the post-event image of 2004 were caused by Typhoon Aere. About 10 % of areas affected by landslidesand 5.5 % of the debris flows/sediment transport areas detected in the post-event image of 2005 were caused by Typhoon Matsa.

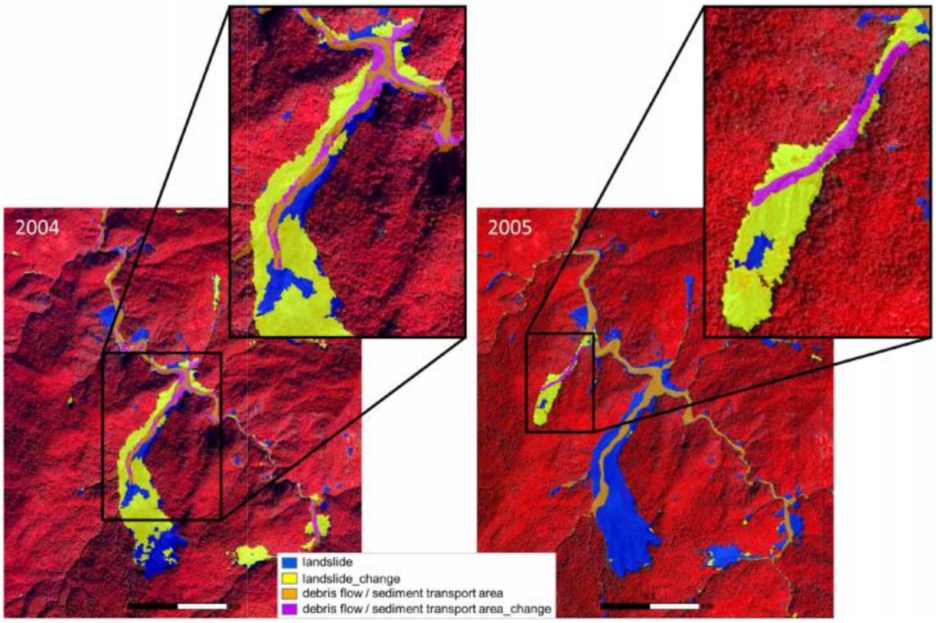

Figure 3: Result of the class-specific object-based change detection for 2004 (left) and 2005 (right).New landslides are displayed in yellow colour, new debris flows/sediment transport areas in purple.

CONCLUSIONS

The presented method for mapping landslide changes based on remote sensing data aims at a high level of automation and transferability. Changes were mainly recognized based on the relative difference of spectral indices (NDVI, GNDVI). The use of absolute spectral thresholds was minimized.However, further research is needed, especially to improve the differentiation of landslides and debris flows/sediment transport areas. Although debris flows pose a severe threat in Taiwan - they often cause more serious damages than landslides - a comprehensive data base comprising debris flows is still missing. The reason for this may lie in the fact that it is hardly possible to find generally valid properties to describe this mass movement type. For tackling this problem we developed a method to classify debris flows and otherareas where sediment transport happens, which mainly relies on morphological features. To further improve the objectivity, transferability and robustness of the method the common knowledge of a numberof expertscould be transformed into computer-based rules and integrated in the analysis. Such aknowledge-based landslide mapping system was recently proposed by Eisank et al. (12).

The detected landslides in the post-event images from 2004 and 2005 were validated by comparing them to manually derivedlandslide maps. Such data setsare often the only reference available, but cannot constitute a completely true reference (13) as their generation depends on the skills of the interpreter, the underlying data, on which scale the reference was obtained and on the purpose of the manual mapping.

Semi-automated object-based change detectionapproaches can, for example, be used for the regular update of landslide inventory maps. Furthermore, areas potentially susceptible to landslides may be identified by retrospective analyses of past landslide events. Results might be of interest for local stakeholders and decision makers, as information on the location and spatial distribution of both new and re-activated landslides can be valuable for disaster prevention and risk management.

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